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Review Article

QUANTITATIVE ANALYSIS OF BIOLOGICAL NITROGEN FIXATION IN VARIOUS MODELS OF LEGUMES AND THE FACTORS INFLUENCING THE PROCESS: A REVIEW

SAMEER SHARMA, ANIKET MALAGE, SIBI G.*

Department of Biotechnology, Indian Academy Degree College-Autonomous, Bengaluru, India, *Head of the Department, Department of Biotechnology, Indian Academy Degree College Autonomous, Bengaluru, India
Email: gsibii@gmail.com

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ABSTRACT

Biological nitrogen fixation refers to the biological reduction of dinitrogen gas to ammonia under normal temperature and pressure. Leguminous crops can combine this abundantly present gas of the atmosphere, which has proven to be beneficial for both the crops themselves and any other succeeding crops growing in the same soil, thereby downsizing the utility of nitrogenous fertilizers. Several techniques are available for the direct quantitative measurement of legume biological nitrogen fixation in the field and controlled environments. However, these are time-consuming and therefore, costly and generate data relevant only to the time and place of measurement. As an alternative, legume biological nitrogen fixation is calculable by either empirical models or dynamic mechanistic simulation models. Comparatively, simulation by a dynamic model is calculable for quantifying legume biological nitrogen fixation, because of its capability to simulate the response of N fixation to a good vary of environmental variables and legume growth standing presently. In this review, an attempt was made to discuss and compare the strategies used to estimate the potential N fixation rate, and therefore the response functions to simulate legume biological nitrogen fixation in nine widely cited models over the last thirty years. Further, assessing their relative strength in simulating legume biological nitrogen fixation with varying biotic and abiotic factors and determines the discrepancies between experimental findings and simulation was carried out. In conclusion, this review clarifies, the current progress in legume biological nitrogen fixation quantification in simulation models, and guides their development, combining elementary experimental and modelling work.

Keywords: Leguminous plant, Nitrogen fixation, Nitrogen-fixing bacteria

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INTRODUCTION

Nitrogen is present in the atmosphere in its molecular form. In this conformation, it comprises of two nitrogen atoms bonded to each other by a triple bond. This contour of nitrogen is inert. To be biologically active the nitrogen needs to combine with other atoms to form compounds like ammonia (NH_3) or nitrates (NO_3) that can be utilized by living organisms for the conglomeration of vital biomolecules like proteins and DNA. The chemically inert nitrogen gas of the atmosphere can be converted into a biologically active form by the course of biological nitrogen fixation. Thus, biological nitrogen fixation may be defined as the process by virtue of which the inert molecular nitrogen gas present in the atmosphere is converted to a biologically usable form in the soil with the aid of microorganisms. Nitrogen fixation refers to the combination of the inert gas with other atoms, generally leading to either oxidation of the gas-producing nitrates or reduction of the gas-forming ammonia. The reaction involves breaking of the triple bond between the nitrogen atoms with nitrogenase enzyme acting as a catalyst along with the aid of 8 electrons and 16 ATP molecules, ultimately leading to the production of ammonia and hydrogen gas. Biological Nitrogen Fixation can hence be considered as the first step of the Nitrogen Cycle. Nitrogen (N) applied in fertilizers or manure that are not concerned by crops will be free into the atmosphere as greenhouse gases [1] or leached into groundwater [2, 3], with resulting environmental implications.

The scientific discipline utilization of biological nitrogen fixation contains a long history. In biological science and agroforestry, nitrogen-fixing utile trees have become vital and additional research is required to optimize their use. The field contains a long tradition of applied biotechnology using legume inoculation for enhanced nitrogen fixation and yields. Legumes are well known for their rhizobial symbiosis that introduces nitrogen into the global nutrient cycle [4]. There are many techniques available for measuring legume biological nitrogen fixation in the environmental field [5, 6]. Models can test how legumes can be used to meet environmental and production goals [7]. These strategies can reveal the response of N fixation to variable factors in real things; however, they are restricted to the conditions prevailing at the time of measure and can't be accustomed to predict N fixation. Thus, there is a desire for strategies to predict legume biological nitrogen fixation quantitatively to assist build choice concerning developing and managing property farming schemes. Estimating N fixation from crop yield or empirical models supported historical crop knowledge will be used; however, these are restricted to a selected site for an equivalent crop. Modeling is probably an improved tool to grasp and quantify legume biological nitrogen fixation because it relies on data of the mechanisms concerned, climate and management, and might accurately represent variations in legume biological nitrogen fixation beneath totally different things. A further complication is that the mathematical functions accustomed to simulate legume biological nitrogen fixation vary between models. For example, the rate of potential N fixation is estimated either by plant N demand and uptake [8, 9], nodule biomass [10, 11], root biomass [12, 13] or aboveground biomass [14, 15]. Also, the response of N fixation to soil mineral N concentration in the root zone, which is closely correlated to N fixation and thus the benefit to soil N fertility from legumes [16], differs between models.

Nitrogen fixation is either very sensitive [11, 17] or tolerant [18, 19] to high soil N concentration in different models [8]. In this paper, we tend to elaborate on the modeling methods published for quantifying legume biological nitrogen fixation by grain and forage legumes. Additionally, to distinguish the different schemes and functions used to simulate the response of N fixation to organic and analyze their relative strengths and weaknesses was reviewed. Further, an attempt was made to determine gaps in the current models and create suggestions to boost the simulation of legume nitrogen fixation in future models. A systematic search was carried out in Pub Med, Scopus and Web of Sciences using a combination of Boolean operators. Peer-reviewed papers in English on the

keywords related to biological nitrogen fixation were retrieved and evaluated based on titles and abstracts. The retrieved papers were managed using Mendeley and the data were consolidated.

Environmental parameters regulating biological combination of nitrogen in leguminous plants

Advance method of legume biological nitrogen fixation is stricken by environmental conditions like temperature, water content, N concentration, root zone hydrogen ion concentration, plant nutrient standing together with C and N substrates in roots, and genetic variation in potential N fixation capability. It is conjointly stricken by organic plant process standing like phosphorus (P) and a metallic element (K) levels that management nodule growth and enzyme activity directly or indirectly [20]. During this article, we tend to focus solely on however legume biological nitrogen fixation responds to environmental conditions and plant C and N substrates intending to improve models. Although here, we tend to only elaborate on this subject in broad terms, several recent review articles cover this space in a lot of greater detail [21]. As may be wanted from the quantity of genes concerned, the consecration and restraint of bacterial nodulation genes are under tight regulative management and could be a major issue affecting host specificity and retort to environmental parables [22].

Soil temperature

Generally, the heat content of the soil prevents the ability of Leguminosae members to biologically combine nitrogen by exercising its control on nodulation, nodule establishment, and nitrogenase activity once it is either too lofty or too crouched [23, 24]. Temperature subsumes salient clout on the endurance and tenacity of rhizobial strains in soil. Soil temperature within the root zone is one amongst the dominant factors for nodulation and establishment. For instance, the nodulation of arrowleaf clover (*Trifolium vesiculosum* Savi.) is increased at a root temperature of 25 °C compared there with growing at each 18 °C and 32 °C [25].

However, the retort of nodule initiation to soil temperature alters between species and varieties. In soybean (*Glycine soap* (L.) Merr.), a lot of nodules square measure created within the pristine extension phase at 25 °C, whereas 20 °C is perfect for nodule length once nodule procreation is concluded as to 15 °C and 30 °C [26]. In distinction, nodule formation is increased with augmenting temperature within the range of 10–35 °C for trefoil (*Trifolium repens* L.) no matter the varieties and, therefore the rhizobia strains [27, 24].

There is an outsized variety of examination on the riposte of N fixation in temperature in legume crops, scruple temperatures for N fixation dissent amidst species from 2 °C to 10 °C, and usually tropical and subtropics legumes have surpassed scintilla temperatures than temperate species. Nitrogenase enterprise is tremendously around 12–35 °C and reaches most at 20–25 °C in most legumes. N fixation in subterranean trefoil (Trifolium subterraneum L) is extremely active at a good vary of temperatures, from 5 °C to 30 °C; however, ebbs persuasively with cold and nearly ceases at 2 °C. Generally, 35 °C or 40 °C is that the higher restraint of temperature for legume biological nitrogen fixation found that out of a hundred rhizobia of untamed soybean in yellow river delta soils in China, four strains exhibited sturdy tolerance to acidity, pH scale, and salinity, as well as high and low temperatures and conjointly had sturdy nodulation capability [28]. Temperature features a profound influence of N2 metabolism. Little activity is ascertained by vasoconstrictive and warming promotes the microbial N_2 fixation and uptake of mounted gas [29].

Soil water enterprise

In a congruous manner to soil temperature, soil water content within the root zone clouts N fixation over nodule initiation and nodule activity, and gas permeability [30-33]. Soil water paucity impedes N fixation [24, 34], and also, the reticence is invigorated as drought stress becomes a lot more fervent [35]. Besides, water-logging will seriously scale back N fixation over the abasement of the initiation and exercise of nodules [20]. It is tasking to appraise the connection amongst N fixation and soil water standing exactly, thanks to the restrictions of experimental regulates. Stress periods and plant recovery [36, 37]. A sigmoid expression has been used to describe the retort of N fixation by common bean (*Phaseolus vulgaris* L.), black gram (*Vigna mungo* (L.) Hepper and cowpea (*Vigna unguiculata* L.) Walp to soil water stress, illustrating acute senility in N fixation as soil water stress becomes more resolute [38, 14].

Carbon requirement at different growth stages for biological Nitrogen fixation

Photosynthate divide to roots supports nodule growth, provides energy for N fixation, maintains a useful population of rhizobia, and permits the synthesis of amino compounds produced from N fixation [39-41]. The C value of N fixation also varies with growth stages [42, 43], but it is a matter of discussion that the C value will increase [44, 45] or decreases [46] with the course of the legume life cycle. Additionally, the strain of the genus *Rhizobium* could affect the C value considerably.

Periodic changes of biological nitrogen fixation in legume

The amount of legume biological nitrogen fixation changes with physiological growth factors. It is low within the early growth stages, whereas nodules are establishing [47] and reaches the most worth between early flowering and early seed-filling, depending upon the species and growing conditions [48-51]. The ability of legumes to form nodules has been attributed to many soil and biological factors that include levels of mineralizable N, levels of available P, soil reaction in the form of pH, type and vigour of legume [52].

Quantification of legume biological nitrogen fixation

Legume biological nitrogen fixation is also quantified by direct measuring, estimation supported yield or with empirical models or simulation of crop models. The ways accustomed live N fixation directly to this point, like the acetylene reduction/hydrogen increment assay, N distinction, 15N-labelling, and ureide, has been completely reviewed [6, 7]. The review of those ways is on the far side of our focus, and during this paper, we tend to describe and compare methods solely to estimate and simulate N fixation.

Crop growth model

Crop growth models are the computer software system programs that may simulate daily growth (e. g. biomass, yield) and development of crops like wheat, maize or potato. Reckoning on the soil characteristics, climatic conditions and crop species, crop models calculate the daily growth of biomass within the individual plant organs (stem, leaves, roots, grains, etc.) moreover because of the progress of plant development from the sowing to maturity. Additionally, crop model accounts for vital processes within the soil (water and nutrient availability) to simulate crop growth throughout a full season. Furthermore, associate advance model, because the one utilized in, FARM/IT calculate nitrogen mineralization, activity volatilization reckoning on precipitation and soil wetness content. Nitrogen deficiency and drought stress method scales back crop biomass growth and yields. Crop models, like DSSAT-CSM batch and APSIM, are enormously used in examining, estimation, and the prophecy of crop growth and manufacture, on-site step up to topical or national levels.

Analysis with empirical models

Static estimation of N fixation throughout the total growing season could use either economic yield or above-ground dry matter. The proportion of legume if it is intercropped, N derived from N2 fixation and the magnitude relation of the existed N belowground to the fixed N surface. As an alternative, the proportion of fixed N transferred to a relative crop, consumed by grazing animals or lost by immobilization [53]. The second methodology to estimate N fixation is by empirical models supported the correlation of fixed N within the final yield against variables, like harvested dry matter or the proportion of legume in mixed leys. A linear equation has been fitted to the measured information of mixed trefoil and grass swards at completely different sites from four countries. This showed a big correlation between fixed N and also the further dry matter of mixed leys, compared with corresponding pure grass either to cut sward or grazed sward [54]. Kristensen *et al.* [55] established that combined

nitrogen at reap exaggerated precariously with clover dry matter content in the mixed meadow through statistically examining the provisional information from completely different sites with distinct soil sorts and irrigation schemes. The first time an immediate estimation of N fixation, and therefore the parameter values are quite simply measured on-site or calculable from the literature. It doesn't strictly need to associate an adequate dataset for multiple years to work out the parameters. Therefore it is simple to use. However, when determining the parameter values, knowledge from years of abnormal weather ought to be avoided, and therefore the properties of the soil should be comparatively stable year-on-year. As these equations are independent of environmental factors like soil properties and climatic conditions, they are solely applicable and correct for similar sites and average climatic conditions.

Additionally, the parameter values ought to be adjusted if the equations are used for various sites or legumes. In contrast, the second technique relies on statistical correlation and assumes that N fixation contains a strong linear relationship to the variables. It is a lot of intensity to use and might be applied to one specific site or multiple sites with completely different soil varieties, counting on however the empirical relationship is developed and which sites the information was obtained from. However, like the first technique, these approaches are restricted to specific sites as a result of the equation is not ready to represent the interaction between plant and environment mechanistically.

Legume simulation in a crop growth model

The simulation of legume biological nitrogen fixation in soybean developed by [56] Duffy *et al.* [56], searching into the bio-physiochemical transformations of N in tile-drained soil, may well be the earliest mechanistic model involving leguminous N fixation. The rate of N fixation by soybean within the model depends on the basic growth rate. In more recent simulation models of biological nitrogen fixation in legumes, the most popular methodology to estimate the speed of legume and biological nitrogen fixation in a potential or most fixation rate changed by the influence of environmental factors. The potential fixation rate is estimated to support either a demand-uptake mechanism or on the dry matter of plant tissues and is varied with plant growth stages. Environmental factors commonly embrace soil temperature, soil or plant water content, soil mineral N or substrate N concentration in plant tissues, and substrate C concentration in the plant. Alternative factors, like soil pH, salinity and also the supply of alternative nutrients, haven't been enclosed in models to date. In this paper, we tend to review the most-used recent simulation models within which a legume N fixation performance has been enforced.

Dissimilitude in erosion productivity impact calculator (EPIC) and agricultural production systems simulator (APSIM) models

EPIC and APSIM models use variations of the primary definition to estimate the potential N fixation rate. The EPIC model assumes that the entire plant N demand is up to the potential N fixation [8, 9]. APSIM defines essential N concentrations for plant tissues and uses these to estimate N demand by maintaining non-stressed N levels in plant tissues and supporting the N demand of recent tissues. APSIM is a biogeochemical model that can simulate productivity and greenhouse gas emissions. The model uses a scheme inspired by DayCent to calculate the fraction of total nitrification and denitrification that is emitted as N_2O [57, 58]. N fixation is just calculated if N uptake can't meet the plant N demand. Therefore, the potential N fixation is assumed to be the difference between plant N demand and N uptake [6, 15]. The second definition relies on the sturdy relationship between N fixation and either nodule size/biomass [31, 45].

Table 1: Simulation models that indulge legume biological nitrogen fixation

Model	Simulated legume species	Reference
Sinclair Model	Soybean	[14]
Erosion Productivity Impact Calculator (EPIC)	Soybean, cowpea, black gram	[9, 18, 19]
Hurley Pasture Model	White clover	[12, 60, 61]
Schwinning Model	Field pea White clover	[17, 62]
Crop Growth Model (CROPGRO)	Soybean, peanut, dry bean, velvet bean, faba bean, cowpea	[63-65]
SOILN	White clover	[6, 15]
Agricultural Production Systems Simulator (APSIM)	Soybean, chickpea, peanut, mungbean, lucerne	[11]
Soussana Model	White clover	[13]

In addition to direct field measurements, estimates of legume biological nitrogen fixation are based on harvested yield or are derived from easy empirical models. Simulation of legume biological nitrogen fixation by models that incorporate the dynamics of N fixation might be the most effective approach as they will facilitate the North American nation to know the nature of the elaborate relationships between N fixation and environmental and plant factors. Our review has found that the tactic used to simulate legume biological nitrogen fixation most often in recent publications is to change potential N fixation rate by factors like soil temperature, soil/plant water, soil/plant N, plant C, and plant growth stages. Despite this variety of approaches, the simulation of legume biological nitrogen fixation in recent models could also be handily summarized as the influence of soil temperature on legume biological nitrogen fixation is often described by a four-threshold-temperature operate, or a sigmoid cubiform perform within the Hurley Pasture Model [59]. The values of those four threshold-temperatures vary with species and vascular plants. Besides, they clarify soil salinity on the vascular plant.

CONCLUSION

This review critically interprets the ways accustomed quantify legume biological nitrogen fixation by the foremost usually used experimental and modelling approaches. To simulate legume biological nitrogen fixation by totally different models and assesses their relative strength in predicting nitrogen fixation with variable biotic and abiotic factors. The stimulating impact on legume Biological nitrogen fixation at comparatively low levels of soil mineral N ought to be distinguished from the inhibition of legume biological nitrogen fixation by soil mineral N. The simulated inhibition of legume biological nitrogen fixation by soil mineral N could be exaggerated if potential N fixation is changed by functions that embrace nodule biomass and therefore the impact of soil mineral N on potential N fixation. More experimental work is required to characterize the result of each soil water deficit and excess soil water on biological nitrogen fixation legume. The responses of legume biological nitrogen fixation to alternative factors presently absent from all models, like soil pH scale and O_2 porousness, have to be compelled to be enclosed and reinforced with adequate experimental work. Intercropping of legumes either with grain crops or in grasslands, because the presence of grazing farm animals affects legume biological nitrogen fixation within fields. Models of legume biological nitrogen fixation should take a higher account of these vital practical uses of legumes.

AUTHORS CONTRIBUTIONS

All the authors have contributed equally

CONFLICT OF INTERESTS

Declared none

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